The Intracloud to Cloud-to-Ground Lightning Ratio Associated with Extreme Weather over the Contiguous United States

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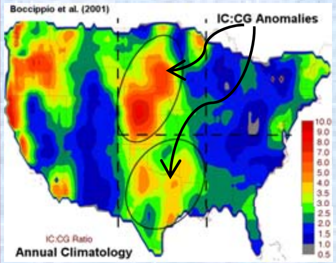
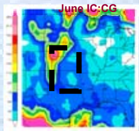
Objective

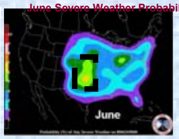
•To estimate the intracloud (IC) to cloud-to-ground (CG) ratio (Z = IC/CG) of a large sample of extreme (i.e., severe) weather events over the contiguous United States (CONUS) using coincident Optical **Transient** Detector (OTD) [or Lightning Image Sensor (LIS)] and National Lightning Detection Network (NLDN) observations .

- **Application**: NOAA GOES-R Geostationary Lightning Mapper (GLM) – do statistically significant differences exist in Z among extreme weather type and intensity?
- **Basic Science**: Boccippio et al. (2001) identified positive anomalies in Z over the north-central and south-central CONUS (see below left). *Large Z long associated with intense updrafts (elevated dipole hypothesis) and severe.*

Annual Climatology of Z=IC/CG







• However, Boccippio et al. note that Z anomaly is noticeably offset from anomaly in severe weather over central CONUS(see above for June).
• Boccippio et al. hypothesize intense (severe) storms comprise a larger fraction of annual climatology of Z in the central CONUS anomaly regions relative to the eastern US where "typical" storms wash out their effects.
• Test Boccippio et al.(2001) hypothesis by estimating Z associated with a large sample of severe storm events. According to their hypothesis, geographic variability of Z associated with individual extreme weather events should not mimic that of the annual climatology, which includes both "garden variety" and "extreme" thunderstorms.

Data

•NASA Optical Transient Detector (OTD), 1995-1999

–Optical total lightning detection (day and night)
–Full CONUS coverage
–Spatial resolution at nadir ≈ 8 km
–Spatial accuracy ≈ 20 – 40 km
–High temporal accuracy
–View time data composited to 0.5° × 0.5° grid (20 – 240 seconds used)
–Flash detection efficiency estimated to be 44% to 56% from local noon to night, respectively. Also a function of gain setting. DE correction made (Boccippio et al. 2000,2001).

•NASA Lightning Imaging Sensor (LIS), 1998-2007

–Optical total lightning detection (day and night)
–Coverage up to about 37°N over CONUS
–Spatial resolution at nadir ≈ 4-5 km
–Spatial accuracy ≈ 6 km
–High temporal accuracy
–View time data composited to 0.5° × 0.5° grid (20 – 100 seconds used)
–Flash detection efficiency estimated to be 73% to 93% from local noon to night, respectively. DE correction made according to Boccippio et al (2002).

•Vaisala's National Lightning Detection Network (NLDN), 1995-2007

- Location, time, peak current, multiplicity of cloud-to-ground (CG) lightning
- Upgraded in 1994-1995 and again in 2002-2003
- CG Flash Detection Efficiency ≥ 90% (Cummins et al. 1998, Biagi et al. 2007). Spatially invariant DE correction made (Boccippio et al. 2001).
- CG location accuracy ~ 500 m (Cummins et al. 1998)
- Potential contamination of +CG data set at low peak current by IC flashes
  - Cummins et al. (1998): Recommend I_{pos} threshold > 10 kA
  - Biagi et al. (2007): no clear threshold but I_{pos} > 15 kA is where # of false +CG reports equals number of correct +CG reports.
  - Experimented with both thresholds in estimation of IC:CG

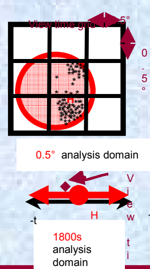
•Extreme weather - NOAA NCDC/SPC Storm Data of CONUS severe reports, 1995-2007

–Tornadoes, large hail (≥ 0.75 inch), strong wind (≥ 50 knots)
–Well known issues with accuracy, particularly temporal (i.e., 5-10 minute errors not uncommon)

Methodology

•For each severe storm report, temporal (seconds) and spatial (degrees) coincidence with OTD (or LIS) and NLDN flashes were assessed
•Flash coincidence sensitivity testing within 900 – 1800 s (1800s shown) and 0.25° – 0.5° (0.5° shown) of each report
•Order 10^5 severe storm reports over CONUS in each of the LIS and OTD domains
•Coincidence with LIS/OTD is between 1% and 10%, yielding 10^3 to 10^4 samples of total lightning activity around severe storm reports
•LIS (20-100 s) and OTD (20-240 s) view times computed as area-weighted averages of 0.5° x 0.5° gridded view times within the analysis area. Used for flash rate calculations.
–Events with view times < 20 seconds discarded.
•Within 0.5° circle centered on extreme weather event during view time (that occurred entirely within 1800 s of extreme weather event),
• DE-corrected OTD_{DE} (or LIS_{DE}) provides total lightning (IC+CG) count
• DE-corrected $NLDN_{DE}$ provides CG count
•Z can range from -1 (no OTD/LIS flashes) to ∞ (no NLDN flashes).

$$Z = \frac{IC}{CG} = \frac{OTD_{DE} - NLDN_{DE}}{NLDN_{DE}}$$



OTD Results

Table of OTD Z = IC/CG by region and severe weather type for both 10kA and 15kA NLDN I_p thresholds (1800s, 0.5°).

Region (# All Severe Events)	Location Latitude, Longitude	Mean Severe Event Z = IC/CG NLDN I_p > 10kA (# Severe Events with Finite Z) (% of All Severe Events with Finite Z)				Mean Severe Event Z = IC/CG NLDN I_p > 15 kA (# Severe Events with Finite Z) (% of All Severe Events with Finite Z)			
		All	Hail	Wind	Tor	All	Hail	Wind	Tor
CONUS (3091)	Contiguous US: Lower 48 States	4.6 (2765) (89.5%)	5.3 (1227)	3.8 (1356)	5.6 (182)	4.9 (2752) (89.1%)	5.7 (1215)	4.0 (1356)	6.0 (181)
East (1207)	Lon > -90°	3.1 (1110) (92.0%)	3.3 (367)	2.8 (688)	5.3 (55)	3.3 (1110) (92.0%)	3.5 (367)	3.0 (688)	5.6 (55)
Southeast (651)	Lon > -90°, Lat < 38°	2.9 (605) (92.9%)	3.1 (224)	2.7 (348)	3.3 (33)	3.2 (605) (92.9%)	3.3 (224)	3.1 (348)	3.8 (33)
Northeast (556)	Lon > -90°, Lat ≥ 38°	3.3 (505) (90.8%)	3.6 (143)	2.9 (340)	8.3 (22)	3.4 (505) (90.8%)	3.8 (143)	2.9 (340)	8.4 (22)
Central (1794)	-105° < Lon < -90°	5.7 (1587) (88.5%)	6.2 (826)	4.9 (638)	5.8 (123)	6.0 (1574) (87.7%)	6.6 (814)	5.1 (638)	6.2 (122)
South-central (1007)	-105° < Lon < -90°, Lat < 38°	4.3 (904) (89.8%)	5.2 (425)	3.4 (413)	4.0 (66)	4.7 (895) (88.9%)	5.9 (416)	3.6 (413)	4.8 (66)
North-central (787)	-105° < Lon < -90°, Lat ≥ 38°	7.4 (683) (86.8%)	7.2 (401)	7.8 (225)	7.7 (57)	7.6 (679) (86.3%)	7.4 (398)	7.9 (225)	7.7 (56)

•Regional behavior in Z persists in all severe categories
•North-central > South-central > South-east ~ North-east (T-test)
•Z anomalies still apparent in severe events
•Regional differences in severe weather magnitude are fairly minor and not always statistically significant or of expected sign.
•Z is not particularly sensitive to choice of I_p threshold
•Mean CONUS severe event Z (4.62) is 57% larger than the CONUS climatological annual mean Z (2.94, Boccippio et al. 2001).
•Hail Z ~ Tornado Z > Wind Z (T-test confirmed)

CDF' of OTD Z = IC/CG (1800s, 0.5°, 10kA) by region

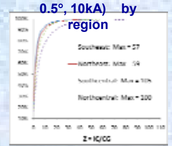
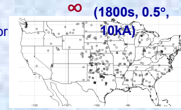


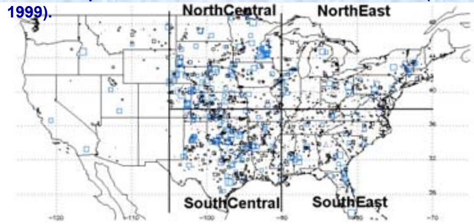
Table of Regional Mean Severe Weather (OTD Domain)

Region	Location Latitude, Longitude	Mean OTD Severe Weather (#) 1995-1999		
		Hail	Wind	Tor
South-east	Lon > -90°, Lat < 38°	1.07" (239)	52.8 kt (147)	0.55 (40)
North-east	Lon > -90°, Lat ≥ 38°	1.07" (155)	55.1 kt (130)	0.72 (25)
South-central	-105° < Lon < -90°, Lat < 38°	1.14" (510)	57.5 kt (234)	0.31 (72)
North-central	-105° < Lon < -90°, Lat ≥ 38°	1.20" (465)	58.5 kt (218)	0.39 (66)

OTD Z = IC/CG = ∞ (1800s, 0.5°, 10kA)

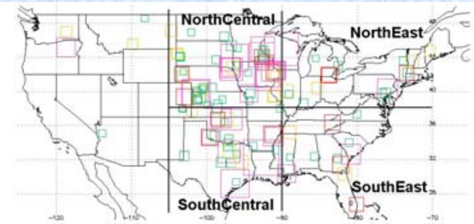


Bubble maps of Z for individual severe weather events (1995-1999).



Z = IC/CG (1800s, 0.5°, 10kA)

< 10
10 - 20
20 - 30
30 - 40
40 - 50
> 50

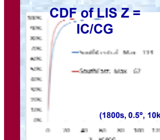


LIS Results

Table of LIS Z = IC/CG by region and severe weather type for both 10kA and 15kA NLDN I_p thresholds (1800s, 0.5°).

Region (# All Severe Events)	Location Latitude, Longitude	Mean Severe Event Z = IC/CG NLDN I_p > 10kA (# Severe Events with Finite Z) (% of All Severe Events with Finite Z)				Mean Severe Event Z = IC/CG NLDN I_p > 15 kA (# Severe Events with Finite Z) (% of All Severe Events with Finite Z)			
		All	Hail	Wind	Tor	All	Hail	Wind	Tor
South CONUS (9753)	LAT < 38°	4.8 (8913) (91.4%)	5.8 (4419)	3.6 (4093)	5.8 (401)	5.1 (8880) (91.0%)	6.2 (4397)	3.9 (4084)	6.2 (399)
Southeast (4590)	Lon > -90°, Lat < 38°	3.4 (4245) (92.5%)	3.9 (1746)	3.0 (2312)	4.8 (187)	3.7 (4238) (92.3%)	4.2 (1745)	3.1 (2307)	5.6 (186)
South-central (4999)	-105° < Lon < -90°, Lat < 38°	6.1 (4537) (90.8%)	7.1 (2612)	4.5 (1718)	6.7 (207)	6.5 (4513) (90.3%)	7.5 (2593)	4.8 (1714)	6.8 (206)

CDF of LIS Z = IC/CG



CDF OTD vs. LIS Z = IC/CG

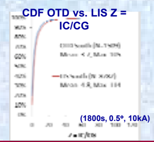


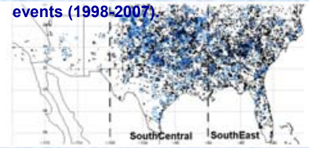
Table of Regional Mean Severe Weather (LIS Domain)

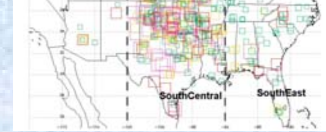
Region	Location Latitude, Longitude	Mean LIS Severe Weather (#) 1998-2007		
		Hail	Wind	Tor
South-east	Lon > -90°, Lat < 38°	1.05" (1859)	53.3 kt (1992)	0.54 (209)
South-central	-105° < Lon < -90°, Lat < 38°	1.15" (2930)	55.5 kt (1465)	0.57 (232)

Bubble maps of Z for individual severe weather events (1998-2007).

< 10
10 - 20
20 - 30
30 - 40
40 - 50
> 50

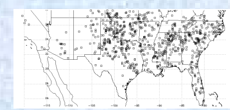
Z = IC/CG (1800s, 0.5°, 10kA)





•Mean LIS Z > Mean OTD Z in the south
• Differences in OTD vs. LIS domain severe weather sample (especially in south-central), location accuracy errors (especially OTD), relative detection efficiency errors.
• Similar to OTD, regional differences in LIS Z persists in all categories.
•South-central Z > South-east Z (T-test)
• Anomaly is still apparent in severe weather events
• Also similar to OTD domain, regional differences in LIS domain severe weather intensity are fairly small and not always statistically significant.
• As for OTD, LIS Hail Z ~ Tornado Z > Wind Z (T-test)
• Z is not particularly sensitive to choice of I_p threshold.

LIS Z = IC/CG = ∞ (1800s, 0.5°, 10kA)



Conclusions

•Regional differences in Z associated with severe weather are apparent: North-central Z > South-central Z > South-east Z (~North-east Z).
•Regional mean Z of individual severe weather events appear to mimic the anomalies present in the annual Z climatology .
•Regional differences in mean severe weather intensity appear to be too small to explain the large differences apparent in regional mean severe Z.
•Assuming mean severe weather magnitude is a proxy for mean storm (updraft) intensity, these results tentatively reject the hypothesis of Boccippio et al. (2001). (That's a big IF, so probably a weak reject). However, need to explore further the effects of temporal/spatial radii with sensitivity tests and to pursue cell-based Z statistics with independent intensity metrics (TRMM PR/TMI). (e.g., Number of non-severe cells in vicinity of severe cells could vary regionally.)
• Hail Z ~ Tornado Z > Wind Z (in most regions but not all – north-central is an exception).
• Peak Z seems to limit at about 100-140. About 7-14% of all severe events were characterized by Z = ∞ during OTD/LIS view time.